IS THIS FOR ME?

Are you a TNA CIC or TECs Ltd. Members who is considering getting a residential scale battery systems? Is your household connected to the electricity grid, with an existing PV system (up to ~4kWpk) and you want to make use of electricity being exported to the grid?

It also applies if you are considering a PV system and wondering whether to include a battery capability or not.

The information provided here should help you make a better, more informed, decision on whether to get such a battery system and if so what size and at what cost. It will not provide a definitive solution for your particular household as this depends how electrical energy is used (i.e. your householders behaviour).

You may only want to get a general overview of the benefits/costs of such systems, relying on expert advice to correctly dimension your specific system, if you decide to get one. Hopefully there is also enough technical detail if you want to dimension the system yourself or check an installer's specification/claims. The latter does, however, needs a certain level of technical understanding .

As well as detailed system/usage dimensions, you can also find some rules of thumb or at least parameters to be considered/measured when deciding on a battery system.

A GENERAL OVERVIEW

What does a residential battery system do?

There are two primary functions your residential scale battery can deliver:

1. Time shifting surplus energy generated by the PV system during the day to be used when the PV system is not generating any electricity.

2. Supplementing your PV generated power (or improving grid power) at peak demand to minimise energy from the grid (or overcoming fluctuating voltage or grid outages).

Both these functions require a battery system which is sufficiently capable/flexible to deliver this in different and changing circumstances.

Why would I get a residential battery system?

As with any expenditure, there are many personal reasons why we decide to buy something. Given quite a wide range of options, the one we chose will also depend on what we are looking to achieve and the budget we have available.

The main reasons for purchasing a residential battery system tend to be:

1. Saving on electricity bills.
2. Reducing our Carbon Footprint.
3. As an area of interest/investigation and/or a social statement.

The first of these requires that the price per unit of electricity (i.e. kWh or MWh) delivered by the battery system during its expected life is less than the unit price if purchased from the grid. Basically it requires a pay-back calculation to be made (see appendix 2).

Similarly, the second reason requires that the Carbon Footprint of the unit of energy from the battery system during its lifetime incl. production and disposal is lower than that for the grid.

The requirements for the third reason listed above are more subjective and are limited only by the balance between the desire to do something and its affordability. This is a lifestyle choice. Nevertheless it is worth understanding what the various parameters are in choosing the right battery system as price and efficacy can vary significantly.

Battery systems are of course also used for off-grid, larger commercial and grid stabilisation purposes. These and other applications fall outside the scope of this paper.

How much will it cost and is it worth it?

Today a good quality, medium sized Lithium-ion battery system for a typical household with and existing PV system (up to 4 kWpk) is priced at ~£6,000 installed.

Whether this is 'worth it' depends on the reasons for having it and the efficacy of the battery system, the subject of this paper. In general, at current grid prices (~£150 per MWh + ~£70 annual connection charges), it is unlikely to make a break-even financial payback, even if the system has been correctly sized/specified. The simplest calculation to demonstrate this is as follows:

- Assuming the PV system is delivering electricity at £0.00 (i.e. it has/will pay for itself) and assuming there is sufficient capacity available from this free source of electricity (i.e. enough unused energy to recharge the battery when needed).

- Then the unit price of the electricity delivered by the battery system = its installed price / its expected life (in units of electrical energy). Currently this comes to ~ £300 per MWh for a typical residential system, almost double current grid prices.

However, all the indicators so far suggest that energy prices will rise in the near future especially when smart meters are introduced and 1/2 hourly price settlement becomes a reality.

Calculating the Carbon Footprint impact for a well sized battery system is given later in Appendix 2. This suggests that a very short Carbon payback period of less than 12 months is a realistic expectation. So certainly a worthwhile thing to do as after this period the system will be reducing your carbon emissions.

THE TECHNICAL DETAILS

What are the components of a residential battery system?

The main components are:

1. The battery itself, ideally with built-in Battery Management System (BMS).
2. A battery charging device, matched to the energy source (i.e. AC or DC source) and matched to the battery (especially if this does not have its own built-in BMS).
3. An inverter/controller to supply mains (AC) power flexibly and in accordance with pre-set rules. This should include a helpful user interface and remote management.
4. An automatic transfer switch if the system is to also function as a backup to the grid (i.e. household continues to be supplied with electricity even if the grid fails).

Each of these components will need to be specified to be operationally and price optimised to the residential property and its occupants. The key parameters for each component will be explained later. Normally these are specified by the installer, but not all installers have the same level of expertise or interest in optimising a battery system.

Measure the existing electrical systems before considering a battery system

In order to achieve the best match (i.e. efficacy of the battery system for the users), avoiding unnecessary cost and likely disappointment, a number of measurements are essential:

1. The current electricity consumption (in kWh), ideally daily, monthly or at least the seasonal variations. Where there are smart meters fitted, the data from these should be used (normally available from the utility company). Note that this should include consumption from sources other than the grid (e.g. a PV system).
2. The household's Base-Load, i.e. the power consumed at night when no one is 'active'.
3. The typical peak power (with seasonal variation if applicable), i.e. what appliances are likely to be on together and how often this occurs.
4. If there is an existing alternative source of electrical energy (e.g. PV), what is this, what is its typical energy output and how much of this energy is used on site/exported to the grid. Ideally these figures should be available daily or monthly/quarterly to establish seasonal variation.

It will also be useful to understand the household's past/future electricity consumption, is it likely to increase/reduce in the future and by how much? Is there a measured track record which confirms this?

The unit prices (for all sources of existing electricity, i.e. including any PV system) and standing charges are also necessary, especially if price/budget is an important consideration. Appendix 1 gives examples of the above measurements.

Providing this information to a knowledgeable installer should help them size and configure the system correctly. TECs Members can use the Dr Watt service to help with both obtaining these figures and advising on system configuration.

How to specify the battery

Only Lithium-ion batteries should be considered as their price/performance and Carbon Footprint are currently ~4x better than Lead-Acid versions. Since these batteries will need to make financial/carbon sense (i.e. make a positive contribution), they will typically need to last at least 10 years and therefore be backed by a reputable/enforceable warranty.

Most reputable batteries intended for a grid-connected household will have a built-in BMS. Note that only if the system is the only source of electrical power (e.g. off-grid application) can the charging of the battery be controlled through an external battery charger which would be configured to double-up as the BMS?

There are several key parameters to consider:

1. The storage capacity (in kWh), this is dimensioned to supply the daily time-shifted energy needed. Typically the battery capacity should be large enough to deliver all the energy needed when the sun is at its weakest during spring and autumn (dimensioning to mid winter or summer may decrease efficacy). The Base-Load x 10hrs + additional evening electricity usage (or typically 50% of the daily consumption, 80% if household is unoccupied during week days) is a good starting point. Having detailed consumption profiles will make this calculation much easier and more accurate.

   Additionally the surplus energy (i.e. that exported to the grid) may limit the size of the storage capacity. It may not be cost effective to oversize the storage capacity if insufficient surplus energy is available from the PV system.

   Batteries come in specific capacity sizes, but can be 'paralleled', they should also not be fully discharged, so at least 10% of the stated capacity is unavailable. Limiting the depth of discharge will have an impact on the expected life of the battery, this data should be available from the manufacturer's literature.

2. The maximum/standard discharge rates, these are given in kW and are typically in a 2:1 ratio to achieve the maximum battery life expectancy. Although this should be chosen to be close to the typical maximum peak power usage in the winter, many households will exceed this demand significantly. Typically 3-5kW is recommended as this figure is also linked to the size (and therefore cost) of the inverter/controller component of the system.

   This is also the figure which can be added to the power generated by an existing PV system to supplement any peak demand during the day.

3. The life of a battery is normally given in maximum full discharge cycles until it reaches a Depth of Discharge (DoD) limit for useful operation. Note that partial discharges are added together. Alternatively this is given in total energy delivered (in MWh) which is equivalent to the battery storage capacity (in KWh) X max. no. full discharge cycles. Typically, a correctly sized system will discharge about 300 times annually. Max full discharges for the specified conditions are 2,000 - 8,000 cycles, so a 10 year battery life span should be expected and is often quoted. It is essential to adhere to the specified conditions to ensure any warranties are not disputed (inverter/controllers keep long term records for verification).

4. Although battery efficiency (ratio of energy-in to energy-out) is an important factor, it is not the most important number. While a battery may have an efficiency of ~95%, a typically system efficiency ranges between 60-80% and is dependent on charger, inverter/controller, temperatures, charge/discharge cycle frequency and rates.

   The efficiency is important in calculating the relationship between the battery capacity and the PV system energy available to recharge the battery. This ultimately defines the likely number of full discharge cycles, essential for pay-back calculations.

How to specify the battery charger

For grid connected systems, and those with battery-backup functionality, the battery charger is typically integrated into the inverter/controller component.

For certain configurations (e.g. off-grid systems), this can be a DC-DC converter and should be sized/configured to manage the battery manufacturer's specifications. The charger should also be matched to, or ideally supplied by, the same manufacturer as that of the inverter component used.

How to specify the inverter/controller

The main parameter for sizing this component is the maximum power required (in kW). This will depend on the sizing of the battery itself and should be set just above the maximum required for the household. The battery charge/discharge rate can be set below this and must not exceed the battery's warranty conditions.

There are now several manufacturers on the market, some integrate this component with the battery component which should make warranty issues easier to address. The user interface, remote control, flexibility in programming/configuration and warranties will be the significant criteria for choosing the make and model.

How to specify the a transfer switch

If this component is required, its size will be determined by the grid connection capacity and compatibility with the inverter/controller component.

Most PV systems use grid-tied inverters, so if the grid fails or exceeds the conditions set by the Distribution Network Operator (e.g. voltage, frequency, number of outages), the PV system will not operate. While it is possible to continue using the PV system's energy where there is another source of 'regulated' electricity (e.g. a battery system), this is only legally permitted when a certified transfer switch is also installed.

The typical price of a G59/3 compliant switch is ~£1,500, this is likely to make a financial pay-back even more challenging unless grid electricity prices start to rise significantly.

Sizing and location of a battery system

Most of the sizing for the individual components has been explained above. Appendix 2 has some further practical numbers from recently installed systems.

The physical size of a battery system can be quite large (1.5m x 1m x 0.5m). This and the fact that these systems will generate some noise when working (e.g. cooling fans and switching relays) will limit where they can be installed. The battery also operates optimally at ~15^{o}C , so locating these outdoors is not ideal unless the area is adequately temperature controlled.

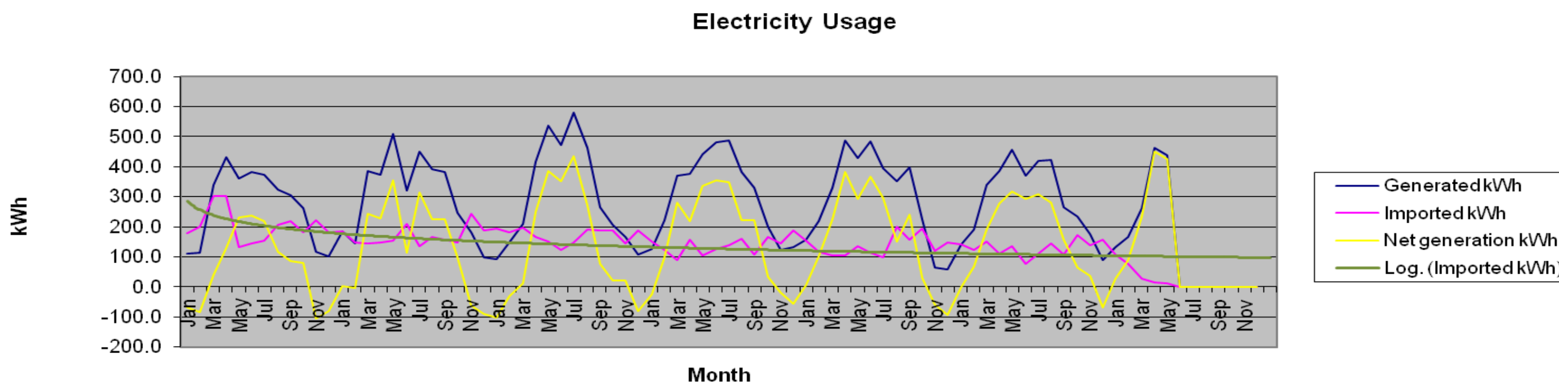
Appendix 1- Example measurements of households with no battery system

Example 1: small house, modest consumption

1. Annual electricity from grid ~ 0.8 MWh @ £146.4 per MWh + £80 annual charges
   Monthly electricity consumption (from grid & PV)= 200 kWh +/- 50 kWh winter/summer variation, so an average daily consumption of ~6 kWh
2. Base-Load = 200 W
3. The typical peak power = ~3 kW
4. PV system = 2.07 kWpk ; annual generation = ~1.75 MWh ; monthly average ~145kWh ranging between 50-200 kWh per month

Example 2: large house, modest consumption

1. Annual electricity from grid ~ 1.6 MWh @ £146.4 per MWh + £84 annual charges
   Monthly electricity consumption (from grid & PV)= 180 kWh +/- 30 kWh winter/summer/visitors variation, so an average daily consumption of ~6 kWh
2. Base-Load = 100 W ; 200 W with visitors
3. The typical peak power = ~4 kW during cooking
4. PV system = 3.78 kWpk ; annual generation = ~3.65 MWh ; monthly average ~300kWh ranging between 50-500 kWh per month ; average monthly export ~80%
5. Chart below starts 2011 with a 3.2 kWpk PV system ; Battery system from Jan 2017



Example 3: average house, average consumption (hypothetical example)

1. Annual electricity from grid ~ 3 MWh @ £140 per MWh + £70 annual charges
   Monthly electricity consumption (from grid & PV)= 300 kWh +/- 50 kWh winter/summer variation, so an average daily consumption of ~10 kWh
2. Base-Load = 200 W
3. The typical peak power = ~6 kW
4. PV system = 4 kWpk ; annual generation = ~3.5 MWh ; monthly average ~300kWh ranging between 50-500 kWh per month

Appendix 2- Example performances/sizing/costs/savings of real/hypothetical battery systems

In general the payback calculation is:
Payback time = (price of new system) / (annual cost of old system– annual cost of new system)
similarly for Carbon = (Embedded Carbon to manufacture system) / (current annual CO2 emissions – new annual CO2 emissions)

To save money or Carbon, the payback time must be longer than the expected life of the system, otherwise the two most common reasons for installing a battery system are not achieved.

The following examples use the formula above to establish how close current battery systems can be in at least breaking even. Annual costs whether £ or kg of CO_2 can be a bit tricky to work out, so a number of assumptions have been made which may differ in some cases and very likely in the future as grid electricity gets decarbonised and energy price inflation accelerates.

<u>Example 1: small house, modest consumption</u>
Battery capacity to cover daily winter usage = 200W x 10 hrs + 6kWh x 50% = 5 kWh
Note that the PV system delivers an average of ~4.8 kWh daily. Allowing for ~30% extra to cover battery system losses, would enable the battery system to supply most of the daily electricity, but mainly during the summer months.

The battery system chosen: 3.3kWh battery capacity ; 10MWh expected lifetime (or ~3,000 cycles) ; 3 kW nominal battery and inverter/controller power; expected annual cycles ~150

Based on the formula above:
£ payback time = (£3,700 installed price of battery system) / ((0.8 MWh - 0.4 MWh expected with battery system) X £146.4 per MWh + £80) = ~27 years

Given the battery is expected to last ~10 years, this system does not currently make financial sense. However, further reductions in grid-imported electricity and an increase in its unit price will bring the payback figure closer to the expected lifespan of the battery.

It is also useful to consider that the inverter/controller and all components other than the battery itself are likely to have a 20 year lifespan. The battery makes up about 60% of the overall price, however, this has not been included in the above calculation which would effectively increase the expected life to ~ 14 years.

Carbon payback time = (~2 kg CO2 per kg of steel/plastic X (30+45+5kg)) / (0.8MWh - 0.4MWh) x 430 kg CO2 per MWh = ~ 6 months

The Carbon payback time uses a simple approximation of embedded Carbon based on materials, this may vary significantly between countries of origin for the materials/manufacture, but is a reasonable indicator (See TNA's Transition Streets programme for references). Since the embedded Carbon in creating the grid that makes and delivers our electricity has not been included in the calculation, the assumption on embedded Carbon for the battery system is considered to be more than reasonable.

Example 2: large house, modest consumption (see figures used from appendix 1)

Battery capacity to cover daily winter usage = 100W x 10 hrs + 6kWh x 60% = 4.6 kWh
Note that the PV system delivers an average of ~10 kWh daily. Allowing for ~30% extra to cover battery system losses, would enable the battery system to supply most of the daily electricity for most of the year.

The battery system chosen: 6.5kWh battery capacity ; 20MWh expected lifetime (or ~3,000 cycles) ; 4.4 kW nominal battery and inverter/controller power; expected annual cycles ~200

Based on the formula above:
£ payback time = (£6,000 installed price of battery system) / ((1.6 MWh - 0.5 MWh expected with battery system) X £146.4 per MWh + £84) = ~25 years

Given the battery is expected to last ~10 years, this system does not currently make financial sense. However, further reductions in grid-imported electricity and an increase in its unit price will bring the payback figure closer to the expected lifespan of the battery.

It is also useful to consider that the inverter/controller and all components other than the battery itself are likely to have a 20 year lifespan. The battery makes up about 60% of the overall price, however, this has not been included in the above calculation which would effectively increase the expected life to ~ 14 years.

Carbon payback time = (~2 kg CO_2 per kg of steel/plastic X (50+45+5kg)) / (1.6MWh - 0.5MWh) x 430 kg CO_2 per MWh = ~ 5 months

The Carbon payback time uses a simple approximation of embedded Carbon based on materials, this may vary significantly between countries of origin for the materials/manufacture, but is a reasonable indicator (See TNA's Transition Streets programme for references). Since the embedded Carbon in creating the grid that makes and delivers our electricity has not been included in the calculation, the assumption on embedded Carbon for the battery system is considered to be more than reasonable.

Example 3: average house, average consumption - hypothetical example (see figures used from Appendix 1)
Battery capacity to cover daily winter usage = 300W x 10 hrs + 10kWh x 60% = 9kWh
Note that the PV system is assumed to be capable of delivering this capacity daily (+ ~30% extra to allow for battery system losses) for only half the year even with the household mostly unoccupied during the day, this despite an average export of ~80% during that period.

The battery system required: 10kWh battery capacity ; 30MWh expected lifetime (or ~3,000 cycles) ; 5 kW nominal battery power; 6 or 9 kWh inverter/controller nominal power should be considered as consumption is unlikely to be reduced and an additional battery may be added in the future; expected annual cycles ~300 as relatively more days where PV system will not fully recharge the battery.

Based on the formula above:
£ payback time = (£9,000 installed price of battery system) / ((3 MWh - 0.5 MWh expected with battery system) X £140 per MWh + £70) = ~21 years

Carbon payback time = (~2 kg CO_2 per kg of steel/plastic X (75+65+5kg)) / (3MWh - 0.5MWh) x 430 kg CO_2 per MWh = ~ 2 months

The Carbon payback time uses a simple approximation of embedded Carbon based on materials, this may vary significantly between countries of origin for the materials/manufacture, but is a reasonable indicator (See TNA's Transition Streets programme for references). Since the embedded Carbon in creating the grid that makes and delivers our electricity has not been included in the calculation, the assumption on embedded Carbon for the battery system is considered to be more than reasonable.